MACHINE VISION FIRE DETECTION TECHNOLOGY

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BY

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EXECUTIVE SUMMARY - MACHINE VISION FIRE DETECTION SYSTEM

The paper will briefly outline problems with existing optical (ultraviolet and infrared) fire detectors and then presents a new type of detection technology. The new technology is called machine vision and has resulted in the development of the Machine Vision Fire Detection System (MVFDS). A prototype MVFDS will be demonstrated. It is based on work performed by the Air Force Fire Research Laboratory located at Tyndall Air Force Base.

The two most important requirements of fire detectors used in ordnance operations are fast detection of a pyrotechnic/propellant fire event and reliable, false alarm-proof operation. It is of the utmost importance to identify the event in time to apply the suppressant to the developing fire event before a catastrophe situation occurs.

It is also important that the detector does not false alarm to a nonfire event, which could result in an extended downtime of the fire protection system and production line, financial loss, and adverse environmental impact.

It has been proven in tests with the MVFDS that there are certain unique characteristics that can distinguish fires from possible false alarm sources. This is done accurately, rapidly, and unequivocally with the algorithms/software developed in this system and implemented with the computer and camera hardware identified in this study. The MVFDS capabilities provide for a major increase in fire detector immunity to false alarms, and greater fire protection system reliability.

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KVFDS was originally developed by the Air Force Fire Research Laboratory to replace optical fire detectors in large aircraft hangers. MVFDS is being evaluated for use in fighter aircraft.

The application of MVFDS technology to ordnance fire protection requirements will be evaluated under a project being funded by the U.S. Army Project Manager for Ammunition Logistics. Technical assistance is being provided by the U.S. Army Armament, Munitions, and Chemical Command Safety Office.

I. Introduction.

1. The two most important requirements of the fire detector are fast detection of a pyrotechnic fire/explosive event and reliable, false alarm-proof operation. It is of utmost importance to identify the event in time to apply the suppressant to the developing fire event before a catastrophic situation occurs.

2. It is also important that the detector does not false alarm to a nonfire event, thus causing the accidental release of the suppressant, which could result in an extended downtime of the fire protection system and production line, financial loss, and adverse environmental impact. Increasing knowledge of the effects of certain types of fire extinguishing agents on the 'atmosphere and water aquifers is increasing awareness of the severity of the environmental impact.

II. Optical Fire Detectors:

1. The types of detectors used over the past 15 years in monitoring ammunition maintenance, storage, renovation, rework, processing, and manufacturing activities are basically the same detectors used for hydrocarbon fire detection, such as in commercial and military aircraft facility applications. These conventional detectors are typically single-band infrared (IR), single-band ultraviolet (UV), and, recently, a combination of both UV and IR. Their operational spectral bands are primarily those associated with hydrocarbon-based fires. The intensity of these radiations is used as a criterion to determine the presence of a fire of some minimum size at some distance. Due to the $1/r^2$ law it is impossible for such a detector to determine actual size, location, or even direction.

2. UV Detectors:

a. Historically, the UV detector has been used for pyrotechnic and propellant fire detection for the past 15 years. Its operational characteristics have been documented many times in reports pertaining to this fire protection problem. Because of its 'Geiger-Mueller' detection morphology, it is a very sensitive detector that can respond to either a photon of energy equal to or greater than some 'work function' energy associated with the cathode material, or a charged particle that can interact directly with the gas molecules.

b. When a photon strikes the cathode, usually tungsten, an electron is emitted.

Tungsten has a work function that will allow, as a minimum, a photon of wavelength 0.245µm (245nm) to cause an electron to be emitted from the cathode. The emitted electron is drawn to the positively-charged anode and, enroute, strikes gas molecules which are then ionized, thus resulting in a current between cathode and anode. An avalanche/discharge occurs which can be interrupted by switching the power on and off or by reversing the charge on the cathode and anode.

c. The glass envelope, usually quartz, is opaque to wavelengths shorter than about 185nm. Therefore, the spectral UV sensitivity of the UV detector is usually between 185 nm and 245 nm, although the cutoffs extend to longer and shorter wavelengths. This type of detector is a relative intensity detector, that does not know the nature, direction, distance, or spectral irradiance of the source. It cannot discriminate spectral energy flux (spectral irradiance), because it will respond to all energies equal to or greater than the specific work function of the cathode and to any source that causes ionization of the fill gas(es) to occur.

d. One problem is that this type of UV detector may be too sensitive to extraneous UV, charged particles, such as cosmic rays, and other ionizing radiations. To circumvent this sensitivity problem, the electronics can be programmed to activate an alarm/suppressant dump only when the count rate reaches some minimum level over some gated time sequence, which is normally above the estimated background count rate or other possible count rates caused by nonfire sources.

3. IR Detectors

a. In addition to UV and visible radiation, fires also produce substantial amounts of IR radiation in the near and mid-IR regions. Most of the emission characteristics pertain to 'blackbody' emission which covers a broad range of the IR spectrum. Some “species - distinct” emission “spikes” occur, especially near 4.4µm. This emission characteristic is due to carbon dioxide. It is also an important fire feature to monitor because the atmosphere absorbs solar radiation in this wavelength region, thus minimizing the background. Another “window” region, sometimes used for IR detection, is near 1.2µm.

b. IR detectors can be very sensitive to almost any “hot” body, because this body radiates across a broad spectrum of the near and mid-IR spectrum, taking the appearance of a bell-shaped curve whose peak intensity corresponds to a wavelength that varies with temperature. Also, IR detectors can “measure” the relative spectral radiance from an event, thus being able to associate “intensity” with relative size and/or distance of the fire source. UV detectors cannot function in this manner due to the work function of the material of the cathode and the cutoff energy of the tube's glass.

c. IR detectors, used in hydrocarbon fire detection, have not demonstrated, to a great degree, reliability to discriminate fire from hot bodies and nonfire sources. Two basic types of sensors are used in these detectors: thermopile and pyroelectric. The thermopile is similar to a thermocouple. Because many “thermocouples” can be connected in series on the same chip, such a detector can be very sensitive. They are, however, very sensitive to ambient temperature changes.

d. Pyroelectric detectors use photodiodes and operate on the basis of time rate of temperature change. The output depends upon the time rate of change in the detector's temperature rather than on the detector temperature itself. It is constructed of a pyroelectric crystal, such as lithium tantalate or ceramic barium titanate. When these crystals are exposed to thermal gradients, they produce electrical current.

e. One characteristic of fire is “flicker.” Flicker is the result of dynamic behavior of the flame and produces an intensity variation in the IR and invisible in the range of 1-20 Hz. Because of this fire flicker property, almost all IR fire detectors require a flicker to exist in the IR signal processing. However, a flicker can respond to any motion such as walking or a moving vehicle in between the detector and the nonfire IR source to cause a false alarm.

4. False alarms:

a. As discussed above, the basic threshold of a fire detector is the spectral irradiance value set for the source to be detected, at its specified maximum distance from the detector. This spectral irradiance is usually determined for a spectral band which corresponds, or overlaps, with the wavelength regions where the detector's sensors operate. For instance, most UV detectors operate in the spectral band of about 185 nm - 260 nm. If the detector is required to identify some type of fire, for example JP-4 fuel, of a certain minimum size at some maximum distance in some maximum time period, the detector is responding to the spectral irradiance from the source at the distance of the detector. If the fire's spectral irradiance is equal to the threshold value at the detector's distance, say “x,” then any spectral irradiance in the same spectral band that is equal to or greater than “x” will cause the detector to alarm. Likewise, any spectral irradiance from any other <u>nonfire</u> source will also cause the detector to respond. This “false alarming” potential is a problem in some applications and, especially, in locations where many nonfire UV and IR sources can exist, either singly or in multiples.

b. Some detectors, such as UV/IR dual-band detectors, are less susceptible to false alarming because, <u>both</u> their UV and IR spectral irradiance threshold bands must be satisfied before an alarm is activated or suppressant is released. In addition, most manufacturers have also added another feature, described earlier, that requires at least the IR radiation to show a modulation of some 'flicker' in the 1-10 Hz range. However, as found in detector false alarm studies, this flicker requirement can also be satisfied simply by moving objects between the detector and the radiation source(s). Therefore, false alarms still occur, but are less frequent with this added flicker requirement.

c. Knowing the spectral irradiance then, of the type of fire/explosion source to be detected at some minimum specified distance in some maximum specified time, it would be a simple task to identify, and possibly eliminate, some, if not all, possible false alarm sources. For UV, IR and UV/IR detectors, this is possible if the spectral irradiance of the possible false alarm source is known. However, the only way to discriminate against such false alarm sources using UV, IR, or UV/IR detectors is to either locate the false alarm source further away from the detector, thus reducing their spectral irradiance to a value less than the threshold value of the fire to be detected, or replacing it with a more benign type, or simply eliminating it. In this manner, a facility can be designed to pose minimum false alarm problems to the fire detection system, especially if the system is a very fast reacting system that is very susceptible to only small values of spectral irradiances.

d. The number of possible false alarm sources covering the electromagnetic spectrum seems to indicate that sources in the visible region would pose a greater false alarm problem than sources in either the UV or IR. This may be true provided the method of detection is based upon intensity only. While UV and IR emissions are commonplace and can come from any direction or even one object; e.g., incandescent 150W lamp, the visible radiation must be in the form of the image of the fire object itself and behave just as the fire object behaves.

5. False Activations:

a. False actuation due to ambient conditions depends upon the detection system being used. Two common types of detectors are in use, UV and IR.

b. Many types of nonfire sources of UV, visible, and IR radiation could make optical fire detectors false alarm and cause the accidental release of suppressant. A list of such sources is included in Appendix A.

c. Eight commercially available detectors, including UV, IR, and UV/IR types, were used in tests to determine the effects of the potential false alarm sources listed in Appendix A. Two types have been used in Army munitions fire detection applications. The detectors tested were set by the manufacturers to the following fire threshold: 2-foot x 2-foot JP-4 pan fire at 100 feet within 5 seconds of the fire attaining full size.

d. A standard 300-watt Quartz Tungsten Halogen (QTH) work lamp, with its glass cover plate on, has an irradiance in the 185 nm to 250 nm band at about 30 feet distance which is equivalent to a 2 foot x 2 foot JP-4 pan fire at 100 feet in the same spectral band. This means that this lamp alone, located at 1 -30 feet from the detector, may satisfy the UV irradiance threshold value required by a fire detector to alarm (in this case to a 2 x 2 foot JP-4 fire at 100 feet or less), provided other factors; e.g., flicker, if any, are also satisfied.

e. If the detector is a multi wave length detector, also requiring satisfaction of a 4.4 µm band IR threshold, this same lamp projects an irradiance out to about 30 feet that equals or exceeds that emanating from the 2-foot x 2-foot JP-4 pan fire at 100 feet. Therefore, a single source may satisfy dual wavelength detection requirements, at least as far as the irradiance values are concerned.

f. Other factors have been built into most detectors today that add features such as 'flicker', rationing, or intensity 'spikes'. These other factors can also be duplicated and are not 'fool proof.' For example, the chopping effect, at low frequencies, can be duplicated by several people' walking in front of a source, a person waving his arms, an irregularly shaped vehicle or mobile platform being moved between the detector and source, a fan, or the chopping effect inherent in certain light sources when they are in start, restart, or failure modes. In some cases, the chopping effect, or flicker frequency requirement built into the detector's response logic has a narrow frequency window. As an example, it will not alarm unless the frequency is 10 Hz or more, while another detector will respond if the frequency is anywhere between 1 Hz and 20 Hz.

g. Analysis showed that the potential of false alarms is much greater when two or more UV and/or IR radiation emitters are present in the FOV of a detector and that the sources have enough radiance in the detector's operating spectral bands to equal or exceed the fire detection threshold irradiances at the distance of the detector.

6. It can, therefore, be concluded about optical fire detectors, in general:

a. Individual radiation sources can trigger a false alarm within the distance over which their irradiance exceeds the detection threshold criterion.

b. Individual radiation sources cannot trigger a false alarm for distances where their irradiance is below the detection criterion.

c. A combination of radiation sources of the kind discussed above can combine to trigger a false alarm.

V. Machine Vision Fire Detector System (MVFDS):

1. Machine vision will be able to offer better discrimination and fast detection. Machine vision, although it operates in the visible part of the electromagnetic spectrum (it can also use IR), relies on intensity and many physical, temporal, and spatial features unique to the fire event. Pattern recognition, artificial intelligence, and computer image processing then play the predominant roles in machine vision fire detection, making it less susceptible to false alarms.

2. Machine vision - general:

a. Machine vision technology provides the means by which information can be automatically extracted by computer processing of video imagery whereby certain preprogrammed patterns, spectral properties, or changes are searched for and, if found, provide the basis of some form of deduction and/or decision. The technology enables reliable and rapid discrimination of objects and phenomena from a very large variety of very similar objects and phenomena having almost identical spectral features in the visible region, although the infrared region can also be used.

b. The system consists of video cameras, real-time video image digitizing interfaces, a microcomputer image processor, and outputs to initiate alarms and suppressant activations. Figure 49 is a block diagram of a prototype hardware configuration.

c. Images/scenes, obtained by either color or black and white CCD (Charge Coupled Device) cameras, can be grabbed, stored, and processed with algorithms at very high frame rates. A machine vision system can be adaptive and 'learn' to recognize images, spectral features, changes, and physical features, and to make decisions based upon these analyses. In other words, machine vision emulates the human process of “seeing” an object, action, or phenomenon with the eye, and determining with the brain what it is and what action to take. A human uses stored knowledge and experience to make these decisions. In a machine vision system, vision with the eye is replaced with a lens and CCD chip. Knowledge is replaced with stored information. Experience is replaced by algorithm processing and comparison. Decisions are based upon satisfying required yes and/or no answers, usually several in parallel. The differences between human and machine vision are: machine vision is much faster, more accurate, and more reliable.

d. The approach taken to detection is derived from physical models for the formation of images of fires and other stimuli. From these physical models, various properties derivable from color or black and white image measurements that can be used to reliably distinguish fires from other events are defined and quantified. These properties can be computed at high-speed and, together with a decision procedure, form the basis of a fire detection system. This system is capable of rapidly identifying fire events (in the few millisecond time range) and determining in real time the corresponding size, growth rate, distance, and location of the event in the scene. The effectiveness of these properties for fire identification has been demonstrated analytically as well as experimentally on real fires, sequences of color images of fires, and possible false alarm sources. 8

e. As stated above, the MFFDS imaging system consists of a CCD camera and the associated optics. The three-dimensional scene is imaged as a spectral irradiance pattern onto the focal plane of the device. This spectral irradiance is proportional to the spectral radiance over corresponding patches in the scene. The CCD imager consists of a two-dimensional array of collection sites that are sensitive to light. Color filters are positioned over spatially adjacent collection sites to provide measurements of the intensities of red, green, and blue light at each location in the image. From these measurements, the camera electronics produce three analog video signals corresponding to each of the component colors. Each of these signals is quantized both spatially and in amplitude by a frame grabber to produce a digital color image. For hydrocarbon fire application, spatial quantization is typically into 480 rows and 512 columns, and amplitude quantization is between 5 and 8 bits per color per pixel. For current fire detection applications, the frame grabber is designed to acquire digital color images and store them in computer memory at the standard video rate of 30 frames per second. Only 3-4 frames are necessary to discriminate fire. Once the frames are in computer memory, the images may be analyzed by a digital processor.

f. The color images acquired by the frame grabber are represented hierarchically as a set of two-dimensional blocks that are processed individually by the fire detection algorithms. Each block corresponds to a specific area in the monitored scene and the size of each block is proportional to the corresponding area in the scene. As frames are acquired, the system control structure incrementally updates the current status and characteristics of each block. Once a contiguous array of blocks is identified as corresponding to a fire event, the system will activate an alarm, if required. When a sufficient number of contiguous blocks are equivalent to a specified fire size, the system will take the appropriate programmed action, such as an automatic release of suppressant at the location of the fire. The detector also produces a video output, thus allowing manual override of any automated suppressant release action, if desired.

g. This process may seem long, but it actually occurs in only tenths of a second for hydrocarbon fire detection applications using commercial, conventional, off-the-shelf hardware/software.

h. The detector is designed to identify a small fire; e.g., 1-2 sq. ft., at a distance of 100 feet in less than 1 second (about 0.3 sec); to determine the fire's size and growth in real time; and to determine the fire's distance and location. In addition to these performance goals, the detector is to be immune to false alarm sources. Such a device will be a major improvement over conventional hydrocarbon fire detectors that rely upon IR and UV emissions and are sensitive to nonfire sources of both radiations.

i. Hardware is presently available that can perform at speeds fast enough to capture three or more frames of an explosion in the 20 ms period. The CCD and CID devices can typically capture a full frame image from 1/60 second to as fast as 1/2000 second.

j. The system provides so many other features in safety and fire protection that it should be closely examined for further development and test. These features include: intrusion detection; simultaneous video surveillance and fire detection; manual override of fire suppression system for slow burning, low threat fires; determination of location, distance and size of fire events, thereby allowing selective discharge of local fire suppressor and thus reducing cost and potential environmental effects.

3. Principle of operation

a. The MFFDS relies on standard silicon CCD color camera outputs in three color (red, green, blue) analog signals. As previously discussed, the MFFDS simulates the detection and logic process of a human being, using only visual sensory input data in the visible region. The video camera outputs one frame -at a time, encompassing the entire scene as covered by the camera's field-of-view (chosen here to be 90 or more degrees). The frame rate is predetermined by the amount of information required to be processed within some interval of time. For purposes herein, the MFFDS operates at a standby rate of one frame every 1-10 seconds until it switches to a fast “event model” where the processing rate is increased to 10-30 frames per second.

b. The MVFDS uses one or more (in a system configuration) cameras to routinely monitor the area/volume being protected. A new frame/scene is 'grabbed', digitized, and stored in memory every 1-10 seconds, replacing the previous frame. This process can continue indefinitely until some change or characteristic in the scene occurs for which the MVFDS was preprogrammed to identify.

c. Immediately upon registering the presence of these radiations, the MVFDS initiates an alarm (if desired) in the facility that a UV/IR source exists and a new frame is grabbed, digitized, processed and stored. This frame now becomes the new base frame, replacing the previous frame in memory. Another frame is then obtained, say within 1/10th of a second or sooner. The computer processing performed on each frame and between frames is described as follows.

(1) The first frame is processed for bright areas consisting of pixels above threshold intensity levels in preselected fire associated color bands. If such a bright area is identified, the pixels occupied are registered in position coordinates and the scan line corresponding to the base of the bright area, on the floor, is also registered. The distance of the bright area from the camera is automatically determined via a stored lookup table that references each scan line number according to its calibrated distance from the detector unit. The calibration is accomplished at installation with the use of markers set at known distances on the floor which correspond to the camera scan line numbers. The size of the bright area is also known, because the size of pixels in the area are automatically known. The bright area is edge enhanced and edge profiled and this information, along with position information, is stored.

(2) If no bright areas are found in the first alert mode frame, consecutive frames are grabbed and processed until one is identified or until the MFFDS decides that no visible fire event exists and, therefore, the UV/IR signals came from a false alarm source. The elapsed time before the MVFDS decides that an event is a false alarm and returns to standby mode can be adjusted, depending on the nature of the fire threat.

(3) For example, assume a bright area is identified in the first event mode frame above. One tenth of a second later the next frame is grabbed, digitized and processed in the same manner as the previous frame. This frame, say F2, is subtracted from Fl, the new base frame, and the size of the remainder of the subtracted bright area determined. Growth, if any, and growth rate are then known over the last one tenth second. The edge profile is determined as well as certain spectral features within the profile of the bright object. Certain pixel continuity features are compared frame-to-frame. All this information is stored and position referenced.

(4) The next frame, F3, is grabbed, subtracted from frame F2, and the bright area(s) processed the same as above for growth, growth rate, edge frequency flicker, pixel continuity between frames, and certain characteristics of the spectral signatures within frame F3 and in comparison to pixels in frames F2 and Fl.

(5) The process continues with frames F4, F5, etc., until the preset conditions that uniquely discriminate fire from other objects/sources/phenomena are all satisfied and the size of the identified fire area reaches the predetermined specified size for the MFFDS to activate the suppressant. Assuming a fire threat similar to the HAS 165-gallon JP-4 spill/fire, the growth and other spatial, temporal, and spectral characteristics could be satisfied within only 0.3-0.4 seconds after fire start.

3. False Alarm Source Discrimination

a. The sources/objects/phenomena that cause conventional detectors to false alarm or to be confused are related to UV and/or IR emissions or reflections. It appears the MFFDS, operating primarily in the color/visible spectrum, are not fooled by such sources.

b. Efforts were made to confuse the MFFDS processing algorithms by the introduction into the scene of various types of bright lights and reflecting surfaces. No misidentifications were made during the test and all were discriminated as nonfire sources. Sources included: lights, welding, matches, aircraft after burners, lighters & similar items outlined in Appendix A.

IV. Utilization and Application of Machine Vision.

1. Comparison of machine vision with conventional fire/flame detectors.

a. The basic difference between conventional detectors (CDS) and the MVFDS is in the quantity and quality of the information generated by each. In the case of the conventional detector, the only information obtained is intensity levels of UV and/or IR radiation at some specific wavelength regions. The detector does not know the direction, distance, location, size, or nature of the source of the radiation. It only knows that it is present. On the other hand, the MFFDS operates in the visible region (like a human being), and knows the source of the light, location, size, distance, spectral color features, movement, association to other objects, and of most importance, <u>that the nature of the light emitting object/phenomena is indeed a fire</u>. Conventional detectors cannot accomplish any of the former and are unsure of the precise nature of the emitting object. There are, therefore, major differences between the two detection concepts.

b. Some specific differences between conventional detectors and the MFFDS are as discussed below:

(1) Fire Detection: Both detect fires, but by different techniques. The conventional detector relies on an indirect technique whereby measurement of UV/IR above a certain present threshold intensity level is equated with a fire of some predetermined/calibrated size at some maximum distance, although the conventional detector does not know anything about the nature and/or properties of the emitting source(s). The MFFDS uses visible light input and computer processing to reach an 'intelligent decision, just as a human being uses his eyes as input and his brain as the information processor. The

former conventional detector technique can be labeled 'indirect' as opposed to the MFFDS direct technique.

(2) Fire Location: Conventional detectors cannot determine where the emitting source is located while the MFFDS knows its distance, size, and position relative to other objects within the field-of-view.

(3) Fire Size:

(a) As stated above, conventional detectors only know that some threshold intensity level of UV/IR has been detected. They are either preset in the factory or calibrated at installation to be able to detect a fire of some size at some distance. Usually a pan fire of some size, say 10-foot x 10-foot, is set at some distance, say 100 feet, and the detector electronics adjusted until it detects the fire within some maximum time period (usually 5 seconds or so, where time zero occurs when the detector is exposed to an already burning 10-foot x 10-foot pan fire). This only assures that a conventional detector will see this level of intensity of UV/IR. A small fire, however, of less distance away from the detector, will be interpreted as being a large fire at some greater distance.

(b) The MFFDS, however, knows the distance of the source, the number of pixels occupied by the source, the size of these pixels, and, therefore, the actual size of the fire event. It can monitor the fire's growth until it reached a size requiring an alarm and/or an automatic release of suppressant. This provides for millisecond action instead of 3-5 seconds or so delayed action as required of conventional detectors today. 13

(4) Time Recruited to Identify Fire Event: As inferred above, conventional detectors can detect UV/IR from a fire instantaneously. But to reduce false alarm problems, they are usually set to respond 3-5 seconds after the fire reaches the threshold size for detection (which can be 10-foot x 10-foot size at 150 feet distance). Conventional detectors normally operate in this 3-5 seconds range and are, therefore, not reliable to detect small fires in very short times (tradeoff of fire sensitivity to false alarm susceptibility). The MFFDS uses the visible to locate and then analyze all the characteristics of the suspect event/object before making a fire decision. From the tests made in this study, it appears that the MFFDS can identify/discriminate a fire of about ½ ft by ½ ft in size at a distance of 100 feet, and that four or five frames of processing is all that is required to determine all the characteristics of the fire event, including its size and location. At one frame every 100 milliseconds, this time period would be about 0.4 to 0.5 seconds.

(5) Immunity to False Alarms:

(a) Conventional detectors respond to many sources of UV and/or IR radiation that are within the wavelength sensitivities of the detector. Conventional detectors are thus susceptible to false alarming to the presence of one or more of the following type of objects/phenomena: lights of many varieties, heaters, aircraft ground equipment (AGE), tools, electric discharges, lightning, welding, aircraft engines from start through afterburner, heat from engine exhausts, x-rays, and many other items.

(b) MFFDS discriminates fire from possible false alarm objects in the visible spectrum by discerning their spatial, temporal, and spectral variations, as well as other features that are unique to fire and not associated with others or combination of sources so far identified.

c. Physical Features

(1) The MFFDS cameras are smaller than conventional detectors and can be mounted in the same manner and configuration. The electronics can be located outside a hazardous location. The MVFDS prototype is about 13-inch x 8 ½-inch x 4-inch, with the capability of multiple detector unit inputs. The first production model would be smaller (about 6 -inch x 8-inch x 4-inch).

(2) The MFFDS can come in two configurations: a single detector unit with computer electronics in one container, and multiple detector units feeding into one computer electronics box, thus enabling small area fire surveillance as well as large hangar surveillance such as B-2 hangars. The number of conventional detectors required to perform a system application such as a hangar is larger than that required by the MFFDS.

(3) Although conventional detectors are not designed to meet stringent military design and performance standards; they can be designed to do so. There may, however, be some costs associated with such redesign and testing efforts. The MFFDS, as a new device, should be designed initially to withstand the environments specified in MIL-STD-810D and MIL-S.D.-461/462, and have the necessary MTBF and system reliability to assure adequate fire protection of mission essential weapon systems and other assets.

d. Producibility/Technical Risk

(1) Conventional detectors are obviously being manufactured and their use has been accepted for many types of fire detection applications. They are designed for commercial applications, and there is no technical risk in the component technology or technical approach employed.

(2) Like conventional detectors, every component required in the MFFDS is now being manufactured and is available within the framework of the video camera and PC computer industry. There exist a multitude of manufacturers of these and related hardware items and the technology is being advanced daily while the costs continually decrease.

2. Compatibility with currently installed fire protection systems.

a. Many new fire protection systems have been installed, either in new construction or as replacements/upgrades to old, less capable technology. The detection units, although they are much more reliable than older single channel detectors, still experience false alarms and false activations. These installed fire protection systems could be made more effective and certainly more reliable if the MFFDS was integrated into their configurations. Conventional detectors with dual UV/IR detectors could be used as input signals to the MFFDS if they were set at very sensitive levels to act as alert switches to the MVFDS camera/computer system to changes from standby mode to fast alert processing mode. For new construction and certain military applications, the MVFDS should be considered on its own merit 15

depending upon the performance requirements and the problems needing solutions.

b. As a retrofit, the MVFDS would have no problems. It could be easily interfaced with currently installed fire control and communication panels. The outputs of the MFFDS could be made to be simple electrical signal inputs to the exiting panels.

c. There are many advantages of integrating the MFFDS with installed conventional detector systems. This includes, of course, increased coverage of fire sources of all sizes at all locations within very short time periods, accuracy of fire location, size, and threat, and elimination of false alarms, and false dumps of suppressant.

d. Another advantage that may be considered is the replacement of any manned TV monitoring system employed for fire observation. The automated capability of the MFFDS far exceeds the ability of a manned, TV monitoring system, saves money, and provides the system reliability and performance levels required to protect valuable assets. This is especially true of those situations where very rapid and reliable fire detection is required to enable suppressant application within seconds. The MFFDS could also act in the automatic and manned TV monitoring mode, as the video output (input to the computer).

V. Conclusions.

1. It has also been demonstrated that there are certain unique characteristics that distinguish fire from possible false alarm sources, that can be accurately, rapidly, and unequivocally determined with the algorithms/software developed in this study and implemented with the computer and camera hardware identified in this study. These MFFDS capabilities provide for major increase in fire detector immunity to false alarms, greater fire protection reliability and, for the first time, very high resolution/identification of small-fires at large distances.

2. The following are supporting conclusions.

a. The presence of UV and IR at wavelengths of 190-300 nanometers and 4.3 micrometers, respectively, might indicate the presence of fire, but not unequivocally. Such precursor information can be used by the MFFDS to 'switch' from standard processing mode into a fast 'alert model' and for selective image processing. In addition, the presence of UV and IR can also function as an 'AND" in the logic decision tree. As the MFFDS is further, developed, the use of this 'AND" and precursor signals may prove to be redundant.

b. Bright areas within a scene can be identified, their positions located, and tracked. Further, the bright areas that are present scene-to-scene when there is no indication of the presence of UV and IR can be eliminated from the stored base scene, thus reducing processing.

c. Bright areas identified when UV and IR are present can be further discriminated by whether their spectral color falls within the selected red, green, and blue color thresholds indicative of fire.

d. Scenes can be captured, digitized, and stored at rates of at least 30 frames per second.

e. The growth and growth rate of a bright area can be determined by frame subtraction of new frames from a base stored frame. Growth is an obvious characteristic of all fire events.

f. The edge profile of bright areas can be determined and measured frame-to-frame for time variations (flicker), which is a characteristic of fire.

g. The spectral variations from pixel to pixel in the same image, and the spectral variations of the same pixels frame-to-frame can be determined. The magnitude of these variations has been shown to be unique to fire and not associated with bright light sources, objects, or phenomena that may be classified as potential false alarm sources.

h. The size and position of the bright object, fire event, can be determined either through multiple detector triangulation or because its distance from a single camera unit is known by the line scan number that identifies its base on the floor. Each pixel dimension is then known because the number of pixels in the horizontal and vertical scan planes are known. The MFFDS can, therefore, actually determine fire event size and position in the process of deciding when and if to-release suppressant. No other detector technique provides such direct information.

i. The algorithms developed previously have' successfully discriminated bright moving lights, colored flickering lights, rotating color lights, strobe lights, highly reflective striped color reflectors, solar spectral reflection surfaces, and other objects and phenomena from fire events.

j. It was possible to obtain and process the data at 0.1-second intervals using PC types of commercial microcomputer hardware.

k. The camera hardware and computer component hardware are off-the-shelf items. There is no technical risk in the full development of the MFFDS. The small-quantity costs for a first generation device are in the same realm as present conventional detectors/logic controllers, and will decrease in time with the advance of technology and larger quantity production runs.

l. A major contribution to fire protection technology and, when incorporated, the MVFDS will provide a valuable tool for reliable fire detection.

m. The MFFDS, in a fast-speed configuration, appears to be a potential high reliability detector of pyrotechnic and propellant events at their early ignition stage. For the application to detection of pyrotechnic/propellent fires and explosive events, the algorithms are simplified according to the physical characteristics of the detonation/fire event.

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APPENDIX A

Possible False Alarm Sources

1. Lights

High Intensity Discharge (HID) Lamps

High Pressure Sodium
Mercury Vapor
Metal Halide
Low Pressure Sodium
Xenon

Fluorescent Lamps (96-inch length)

Cool White
Deluxe Cool White
Warm White
Deluxe Warm White
White
Daylight
Black Light

Incandescent Lamps Quartz Tungsten Halogen

Sealed Beam - Automotive
Headlamp
Spotlamp
Signal
Light Bar
Rotating Lights

Flashlight

Flashlight with Red Lens
Rough Service
Movie Projector
Blue Green Dome Light
Red Light

Vehicle Infrared Light

2. Reflected Light

Solar and/or artificial light reflecting from painted surfaces, metallic surfaces, plastics, standing water, ice, and glass.

3. Natural Phenomena

Sunlight: direct, scattered, reflected
Lightning

4. Electrical Discharge

Arcing

Power Transformers
Motors
Electrical Devices
Faulty Wiring

Flashlamps
Carbon Arcs

5. Nondestructive Investigative Devices (NDI)

Scattered X-rays
Scattered Secondary X-rays, UV, Direct, Reflected

6. Electromagnetic Waves

Communication Devices/Walkie Talkies/Radios/TV
Radar
IR Emission from security surveillance devices
Electric Power Switching
EMI from Electronic Equipment:

Vehicle/Aircraft/Equipment Subsystems
Electronic tools/equipment
Microwave devices
Weapon Systems

7. Personal Items (very doubtfully near facility)

Lighted Cigarette, Cigar, Pipe
Matches (paper and wood)
Butane Lighter

8. Tools/Operations

Welding Operations

TIG
Arc
MIG

Acetylene Welding and Cutting Operations

9. Hot Bodies, Blackbody Radiators

Vehicle Engines, Manifolds, Exhausts, Radiators, Mufflers Ground Equipment Engines, Manifolds, Exhausts, Radiators, Mufflers from such equipment as:

Thermal Heating Blankets/Welding
Radiation Electric Heaters (1.0 and 1.5 Kw with Fan) Radiation Kerosene Heater (70,000 BTU with Fan) Hot Lamps
Hot Welding Materials

10. Security Personnel Weapons

M-16 Rifles
M-60 Machine Guns
M-79 Grenade Launchers
38 Caliber Pistols
12-Gauge Shotguns

11. Fire/Explosive Events Associated with Vehicle and Ground Equipment Engine Wet Starts/Backfires

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